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Lubrication

A Technical Publication Devoted to the Selection and Use of Lubricants

This Issue

AIRCRAFT TURBINE LUBRICATION

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LUBRICATION

A TECHNICAL PUBLICATION DEVOTED TO THE SELECTION AND USE OF LUBRICANTS

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Aircraft Turbine Lubrication

THE new era brought about by gas turbine-powered aircraft has produced a significant impact on the petroleum industry. New and strenuous lubrication requirements challenge the industry in its effort to contribute toward the continued growth of safe, dependable and economical flight. This challenge was met in early turbine engines by the use of light mineral oils. Although still in limited use, these oils were unable to fulfill the requirements of more advanced engines and therefore a new class of oils, synthetics, is in preponderant use today. In the ensuing text the term "aircraft turbine oil" will therefore refer to the synthetic rather than the mineral type.

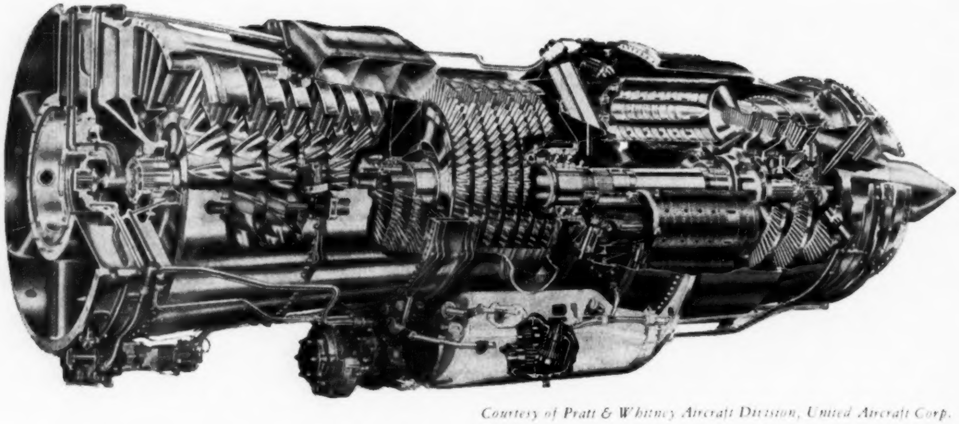
Synthetic oils have been developed primarily for engine use. However, to minimize both the number of oils required to lubricate aircraft and the possibilities of misapplications of oils, engine and airframe auxiliary equipment usually employ the same oil as the main engine. Such equipment includes starters, electrical generator constant speed drives, cabin supercharger drives etc. Whether the equipment is an engine or an auxiliary component, the same fundamentals apply in the demands placed on the oil in the lubrication of gears and bearings. With this in mind, the following comments broadly cover both engines and auxiliary equipment.

The topics discussed herein generally relate equally well to commercial and to military engines. For obvious reasons the text is confined to matters which are not classified under military security regulations. It is pertinent to note that commercial aircraft turbine engines have benefited greatly from earlier development work conducted under military auspices.

The following information is intended to indicate briefly the essentials pertaining to the use of lubricants in aircraft turbine engines. It is emphasized that this is a field in which progress is being made continuously. Consequently, some of the information presented is in the way of an interim status report on progress to date and problems yet to be solved.

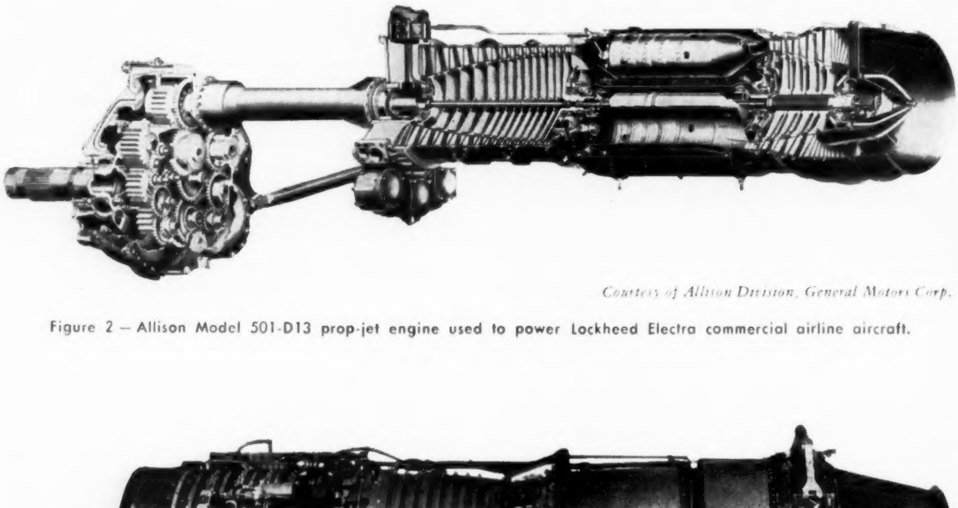
ENGINES AND OIL SYSTEMS

Examples of several turbojet and turboprop engines with diagrams of their lubrication systems are shown in Figure 1 through 5, 10, and 13. The reader's attention is invited to the numerous bearings and gears which must be lubricated. Although the details vary, the oil systems are similar in that they provide an oil supply tank, pressure pumps to deliver oil to points to be lubricated, scavenge pumps to return oil to the tank, and means to control oil temperature and pressure. Provisions are made also for oil filtration and the separation of oil and air vented and pumped from gear and bearing compartments. Engine-driven accessories may have separate oil systems or may employ oil from the main engine oil system. It is evident that oil is an integral component of an engine and that oil performance is critical to the successful operation of the engine.



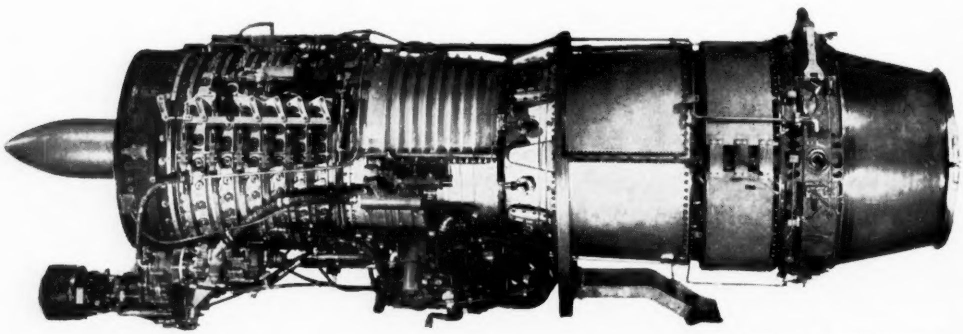
Courtesy of Pratt & Whitney Aircraft Division, United Aircraft Corp.

Figure 1 — Pratt & Whitney Aircraft JT-3 turbojet engine used to power Boeing 707, 720 and Douglas DC-8 commercial airline aircraft.



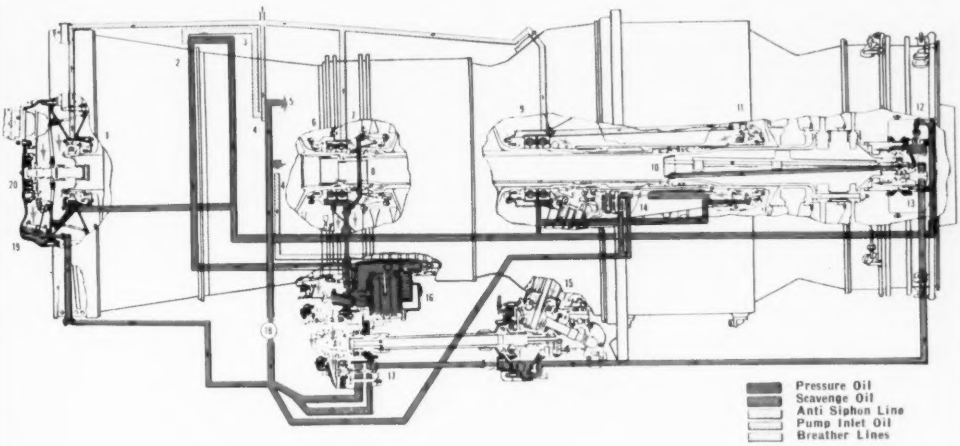
Courtesy of Allison Division, General Motors Corp.

Figure 2 — Allison Model 501-D13 prop-jet engine used to power Lockheed Electra commercial airline aircraft.



Courtesy of General Electric Co.

Figure 3 — General Electric CJ-805 turbojet engine used to power the Convair 880 commercial airline aircraft.



1. No. 1 Bearing
2. Anti Siphon System
3. Breather System
4. Oil Tank Connections
5. Oil Into Tank
6. No. 2 Bearing
7. No. 2½ Bearing
8. No. 3 Bearing
9. No. 4 Bearing
10. No. 4½ Bearing
11. No. 5 Bearing
12. No. 6 Bearing
13. No. 6 Bearing Scavenge Pump
14. No. 4 & No. 5 Bearing Scavenge Pump
15. Accessory Drive Adapter
16. Oil Pressure Pump
17. Main Oil Scavenge Pump
18. Oil Cooler (Not Supplied By Engine Mfg.)
19. Front Accessory Drive Scavenge Pump
20. Front Accessory Section

Courtesy of Pratt & Whitney Aircraft Division, United Aircraft Corp.

Figure 4 — Pratt & Whitney Aircraft JT-3 engine lubrication system.

TABLE I

SUMMARY OF AIRCRAFT TURBINE ENGINE SYNTHETIC LUBRICANT SPECIFICATIONS

	MIL-L-7808C Amend. 1	MIL-L-25336 (ASG)	MIL-L-9236A (USAF)	MIL-C-8188B Amend. 1	British D. Eng. R. D. 2487 (Issue No. 3)	Allison EMS-35
Viscosity, cs. at: 400°F., min.	—	—	3.0	—	—	—
210°F., min.	3.0	3.0	Report	3.0	7.5	7.5
100°F., min.	11.0	11.0	Report	11.0	39 max.	—
–40°F., max.	—	—	—	—	13,000	13,000
–65°F., max.	13,000	13,000		18,000	—	—
Flash Point, °F., min.	400	400	500	350	420	425
Pour Point, °F., max.	–75	–75	Report	–75	—	–60
Mineral Acidity	—	—	—	—	None	—
Gear Tests:						
Ryder, pounds per inch, min.	1,700*	2,800**	2,800**	1,700*	—	3,000
IAE	—	—	—	—	At least equal to Reference Oil	—
Oxidation-Corrosion (72 Hr. at 347°F.)						
Wt. Change, mg./cm.^{2}						
Copper	±0.4	±0.4	±0.4 (48 Hr. at 500°F.)	±0.4	—	±0.4
Magnesium	±0.2	±0.2	±0.2 (48 Hr. at 500°F.)	±0.2	—	±0.2
Aluminum	±0.2	±0.2	±0.2 (48 Hr. at 500°F.)	±0.2	—	±0.2
Steel	±0.2	±0.2	±0.2 (48 Hr. at 500°F.)	±0.2	—	±0.2
Silver	±0.2	±0.2	±0.2 (48 Hr. at 500°F.)	±0.2	—	±0.2
Titanium	—	—	±0.2 (48 Hr. at 500°F.)	—	—	—
Appearance	Stain Permitted	Stain Permitted	No Visible Corrosion	Stain Permitted	—	Stain Permitted
Viscosity Change at 100°F., %	–5 to +15	–5 to +15	—	–5 to +25	—	–5 to +12
Neut. No. Change, max.	2.0	2.0	2.0	3.0	—	1.5
Oxidation-Corrosion (22 Hr. at 284°F.)						
Wt. Change, mg./cm.^{2}, max.						
Cadmium	—	—	—	—	0.2	—
Copper	—	—	—	—	0.2	—
Appearance	—	—	—	—	Slt. Stain Permitted	—
Viscosity Change at 100°F., %, max.	—	—	—	—	±5	—
Neut. No. Change, max.	—	—	—	—	0.5	—
Corrosion (50 Hr. at 450°F.)						
Wt. Change, mg./in.^{2}, max.						
Copper	3.0	3.0	—	3.0	—	—
Silver	3.0	3.0	—	3.0	—	—

* Relative Rating = 78% minimum, basis two determinations

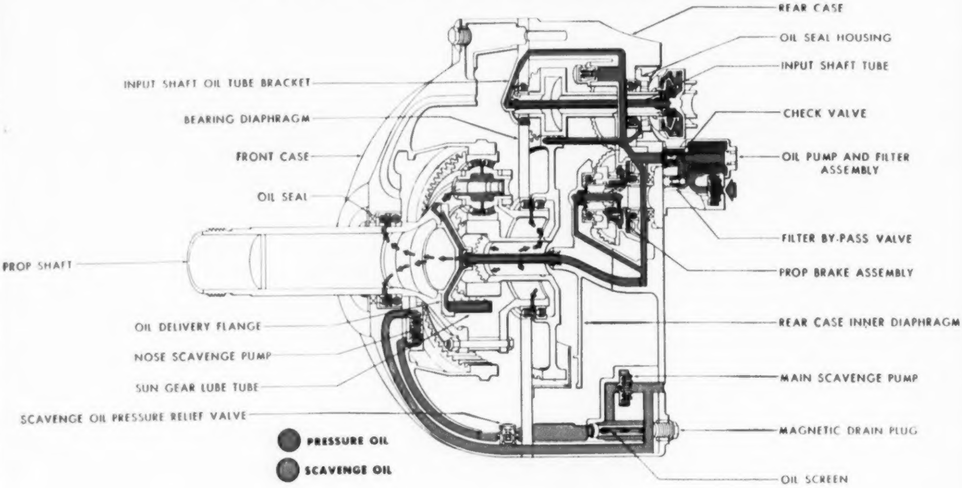
** Relative Rating = 118% minimum, basis two determinations

TABLE I (Continued)

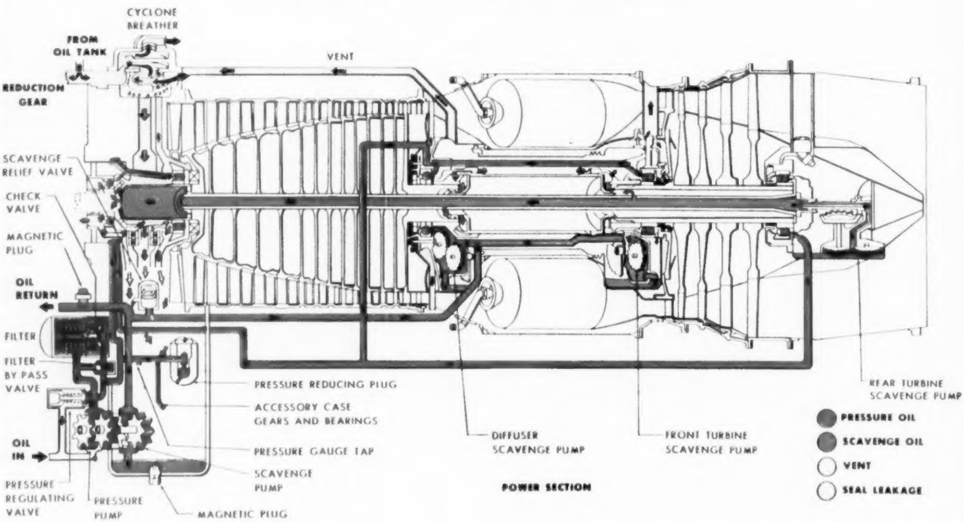
SUMMARY OF AIRCRAFT TURBINE ENGINE SYNTHETIC LUBRICANT SPECIFICATIONS

	MIL-L-7808C Amend. 1	MIL-L-25336 (ASG)	MIL-L-9236A (USAF)	MIL-C-8188B Amend. 1	British D. Eng. R. D. 2487 (Issue No. 3)	Allison EMS-35
SOD Lead Corrosion (1 Hr. at 325°F.), Wt. Loss, mg./in.^{2}, max.	6	6	—	6	—	6
Panel Coking (8 Hr. at 600°F.), mg., max.	80	80	100 (700°F.)	125	—	150
Thermal Stability (24 Hr. at 536°F.) Vis. Change at 100°F., %	—	—	—	—	−10 to +20	—
Shear Stability (168 Hr. Pump Test) Vis. Change at 100°F., %	—	—	—	—	±5	—
Bearing Test:						
Napier	—	—	—	—	Satisfactory at min. of 536°F.	—
100 Hour	—	—	Pass	—	—	—
Bearing Stabilization Temperature	—	—	Pass	—	—	—
Viscosity Stability						
at −65°F., 3 Hr. Change, %, max.	6 (13,000 cs. max.)	3 (13,000 cs. max.)	±5	±5	—	—
at −65°F., 72 Hr. Viscosity, c.s., max.	17,000	13,000	—	—	—	—
Low Temp. Stability at −40°F. (72 Hr.)	—	—	—	—	—	No Gel or Crystallization
Foaming						
Seq. 1-2-3 Volume, ml., max.	100-25-100	100-25-100	100-25-100	100-25-100	—	100-25-100
Seq. 1-2-3 Collapse Time, min., max.	5-3-5	5-3-5	5-3-5	5-3-5	—	5-3-5
Evaporation (6½ Hr. at 400°F.), %, max.	35	35	—	50	Report (392°F.)	Report
Rubber Swelling ("H" Rubber), %	12-35	12-35	—	12-35	—	—
Homogeneity (−65 to 536°F.)	—	—	—	—	Shall Remain Homogenous	—
Compatibility	Pass	Pass	Pass	Pass	Pass	Pass
Storage Stability (12 mo.)	—	—	—	No Separation, 18,000 cs. max. at −65°F.	—	—
(24 mo.)	—	—	—	—	Pass	—
Protection (144 Hr. at 120°F. in Humidity Cabinet)	—	—	—	Pass	—	—
Engine Test:						
Turbojet	Pass	Pass	Pass	Pass	Pass	—
Turboprop	—	Pass	—		Pass	Pass

REDUCTION GEAR SCHEMATIC OIL SYSTEM



POWER UNIT SCHEMATIC OIL SYSTEM



Courtesy of Allison Division, General Motors Corp.

Figure 5 – Allison Model 501-D13 oil systems. Note that the reduction gear and power unit have separate pressure and scavenge pumps. Both sections are supplied from a common oil tank.

TABLE II
PHYSICAL PROPERTIES OF A MIL-L-7808C TYPE SYNTHETIC AIRCRAFT TURBINE OIL

Temperature, °F.	−65	+100	+200	+300	+400
Kinematic Viscosity, cs.	10,498	17.6	5.0	2.4	Below 2
Density, Lb./Gal.	8.16	7.58	7.21	6.76	6.26
Vapor Pressure, mm. Hg.	Below 0.0001	Below 0.001	0.01	0.2	2
Specific Heat, Btu/Lb./°F.	0.35	0.44	0.49	0.55	0.60
Thermal Conductivity, Btu/Hr./Ft.^{2}/Ft./°F.	0.0904	0.0867	0.0844	0.0821	0.0798
Coefficient of Expansion (Cubical), per °F.	0.00045	0.00049	0.00060	0.00070	0.00101
Surface Tension, Against Air), Dynes/cm.	47.3	28.5	24.4	20.4	16.4
Dielectric Constant	4.6	3.9	3.5	3.1	2.6
Foam Volume Formed*					
At Sea Level (29.92 In. Hg.) ml.	0	0	0	0	—
35,000 Ft. (7.04 In. Hg.) ml.	0	0	0	0	—
70,000 Ft. (1.32 In. Hg.) ml.	0	0	0	0	—

*Observations immediately after blowing; MIL-L-7808C method equipment was modified to operate at conditions shown.

OIL DEVELOPMENTS AND SPECIFICATIONS

From the beginning, turbine engines were required by the U. S. Armed Services to be capable of starting at minus 65°F. without the application of external heat. This led to the use of light mineral oils for ease of low temperature pumping. These oils are designated as Grades 1005 and 1010 of U. S. Military Specification MIL-0-6081.

These oils have given satisfactory service in engines where bearing temperatures are of the order of 300°F. or less. With advances in engine development, the lubricants were exposed to higher temperatures. At elevated temperatures, the light mineral oils suffered large evaporation losses and inadequate viscosity. It therefore became apparent that lubricants capable of wider-temperature range operation would be required if minus 65°F. starting capability were to be maintained.

In the search for wider-temperature range lubricants, many classes of synthetic materials were evaluated including polyglycols, silicones, chlorinated hydrocarbons, dibasic acid esters, etc. Information on a number of these materials was given in a previous issue* of this publication. This work indicated the dibasic acid esters (diesters) to be the most promising class of materials. The diesters are prepared by reacting an organic acid with a high molecular weight alcohol. Hydrocarbons such as benzene or cyclohexane can be used as a starting material to produce the adipate diester, castor bean oil for the sebacate diester and animal tallow for the azelate diester. The chemistry of synthetic oils will be treated more extensively in a subsequent issue of this publication.

*Lubrication, April 1954.

U. S. Military Specification MIL-L-7808C, summarized in Table I, covers the type of synthetic aircraft turbine lubricant in most widespread use in the United States today. Both General Electric and Pratt & Whitney Aircraft specify oils of this class for use in modern engines. Such oils are diesters compounded to enhance oxidation stability, corrosion resistance, gear load-carrying ability, etc. Table II elaborates on the actual physical properties of an oil meeting this specification.

The lubrication requirements of certain turboprop engine reduction gears have indicated the need for oils of higher gear load-carrying ability than provided by a MIL-L-7808C oil which is approximately the same as that of MIL-L-6082 Grade 1065 mineral oil. Accordingly, U. S. Military Specification MIL-L-25336 was issued which requires approximately the same gear load-carrying ability as MIL-L-6082 Grade 1100 mineral oil but is otherwise substantially the same as MIL-L-7808. The requirements of MIL-L-25336 are also included in Table I.

British Specification D. Eng. R.D. 2487 covers synthetic aircraft turbine engine oils of somewhat heavier viscosity than U. S. Specifications MIL-L-7808C and MIL-L-25336 since the British requirement for starting is only minus 40°F. and they also require a higher 210°F. viscosity for turboprop engine reduction gear lubrication. This type oil has been specified by British engine builders, including

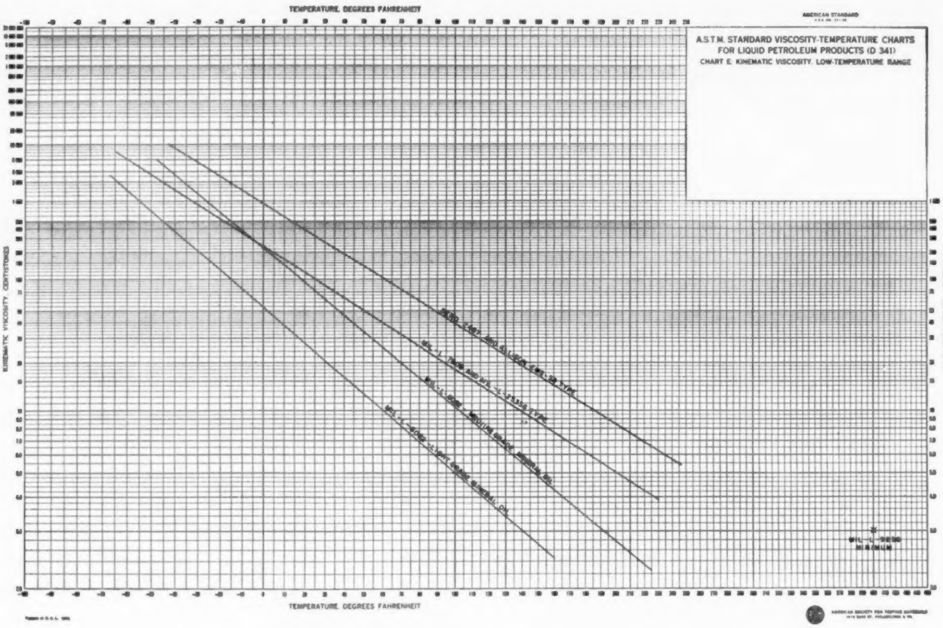


Figure 6 — Typical Viscosity-Temperature Curves for Several Aircraft Turbine Oils.

Bristol, Napier and Rolls-Royce, for use in various engines. The principal requirements of this specification are outlined in Table I along with those of Allison Division, General Motors Corp., Specification EMS-35 covering this class of oil.

Table I also includes information on U. S. Military Specification MIL-L-9236A. This is a target specification for oils of higher temperature capability than required by the other specifications.

U. S. Military Specification MIL-C-8188B, also outlined in Table I, is the rust preventive counterpart of MIL-L-7808C.

OIL REQUIREMENTS

The function of a gas turbine lubricant is to lubricate and cool gears and bearings. Unlike piston engine lubricants, the gas turbine lubricant is not usually contaminated with fuel or fuel combustion products. On the other hand, it is subjected to very high temperatures under oxidizing conditions and must also be usable at very low temperatures. Such severe duty requires that special care must be taken in the selection, compounding and testing of turbine lubricants if satisfactory engine operation is to be attained. The numerous requirements which aircraft turbine oils must fulfill are described below.

Viscosity

Viscosity, the measure of resistance to flow, is one of the most important properties in any oil application and the turbine engine is no exception. At minimum anticipated starting temperatures the oil must be sufficiently mobile to flow into oil pump inlets and to parts to be lubricated. Also, it must not be so viscous as to create such undue drag in gears and bearings that available engine starting torque capacity is exceeded. Experience has shown that for satisfactory performance, oil viscosity should not exceed 13,000 centistokes at the minimum starting temperature. Oil viscosity is also very important at elevated temperatures in providing adequate separation of metal surfaces, as in gears and bearings, and in insuring proper oil flow rates to parts for the purpose of lubrication and cooling.

Oil viscosity is commonly determined by measuring the time for a given quantity of oil to flow through a standard capillary tube at a given temperature. The ideal oil would show no change in viscosity with change in temperature. One of the primary reasons synthetic oils have been adopted for turbine engines in place of mineral oils is that they more nearly approach this ideal. This is illustrated in Figure 6.

It is normal for the viscosity of an oil to change in service. Increases in viscosity can occur due to contaminants in suspension and/or the formation of more viscous oxidation and thermal degradation products. On the other hand, some oils may undergo

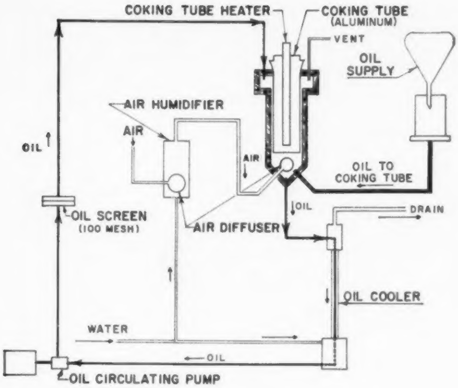


Figure 7 — Schematic diagram of WADC deposition tester. Deposition Number is calculated as the sum of the screen deposit weight (grams) plus 10 times the coking tube deposit weight (grams).

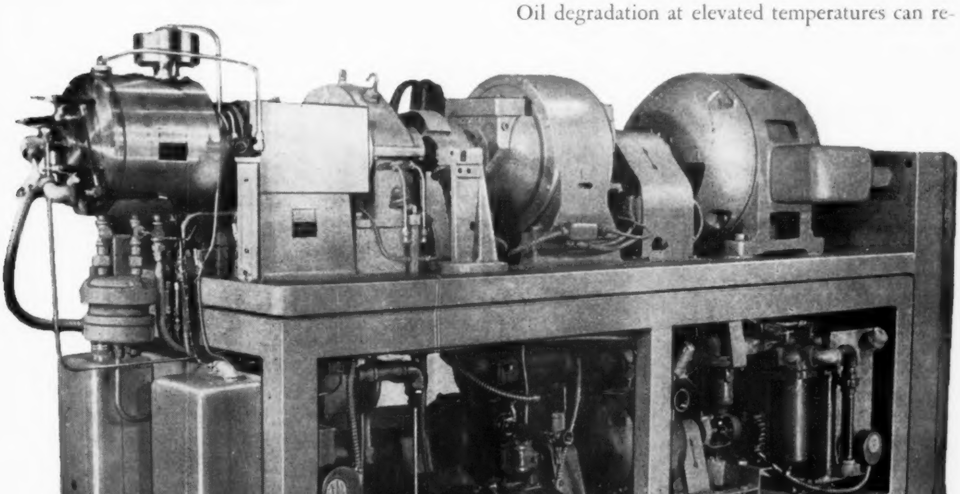
viscosity reductions due to thermal effects and/or mechanical shearing. While the latter is not thoroughly understood, it is commonly believed that the local temperatures generated during mechanical shearing actually cause the viscosity decrease. Regardless of cause, variation of oil viscosity in service must be held within limits to provide proper lubrication.

Viscosity stability at higher temperatures is sometimes evaluated in pump tests which subject the oil to mechanical shearing. The pump test used in British Specification D. Eng. R.D. 2487 is of this type.

High Temperature Stability

Another important oil property is resistance to chemical and physical change upon exposure to high temperatures, particularly in the presence of air, since the oil is exposed to high temperatures in carrying out its task of lubricating and transferring heat from gears and bearings.

Oil degradation at elevated temperatures can re-



Courtesy of EPPI Precision Products, Inc.

Figure 8 — High Temperature Bearing Test head mounted on ERDCO Universal Tester. This tester can be employed also to drive a Ryder Gear Test head.

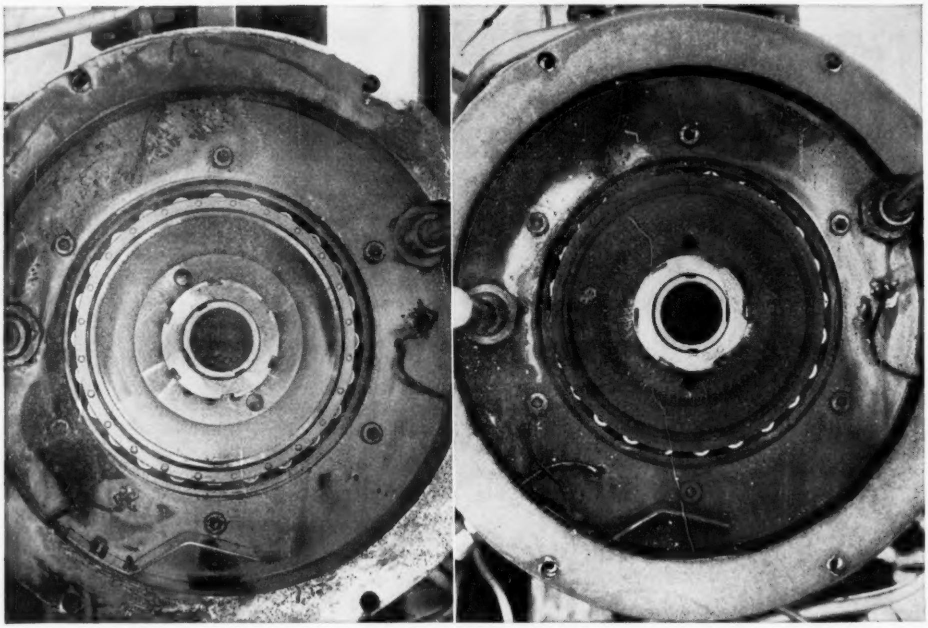


Figure 9 — Results of High Temperature Bearing Tests on a MIL-L-7808 type oil. As shown on the left, deposits on the bearing itself were nil after 100 hours at 300°F. oil temperature. Note copious bearing deposits on the right when the same oil ran only 27 hours at 400°F. oil temperature.

sult from both thermal effects and oxidation. Accordingly, the oil developer strives to devise his formulation to be as resistant as possible to these influences. The results of such degradation can include engine deposits, oil viscosity increase, and the corrosion of metals used in engine construction. Oil degradation can be minimized by avoiding engine hot spots, excessive bulk oil temperatures, mixing with air, and by maintaining adequate oil flow over hot parts.

In the laboratory, a large variety of test procedures is required to study these oil properties. The simplest tests are conducted in special laboratory glassware, while more complex tests are carried out in mechanical equipment which more closely simulates engine operating conditions. Glassware tests include heating and oxidation tests which emphasize oil condition, corrosion tests which indicate the effects of oil deterioration on metals commonly used in engines, and oxidation-corrosion tests which evaluate both oil and metal condition. In certain tests copper is added as an oxidation promoter, although the metal may not be present in engines. These tests indicate an oil's corrosivity to metals in terms of metal specimen appearance and weight change. The effects of these tests on the oil itself are measured by viscosity increase and neutralization number change. The British specification includes a high temperature stability test in which oil is kept at high temperature under a nitrogen atmosphere; oil decomposition is checked by viscosity change. Experience has shown the main utility of these tests is in the control of quality during oil manufacture. They offer only general information in predicting subsequent oil performance in engines.

To overcome this deficiency more elaborate tests are conducted after oils have been screened by glassware tests. One of the earliest of such tests is the Panel Coking test, first developed for reciprocating engine oils. Oil is splashed on a heated aluminum strip for eight hours and the carbon deposit formed on the test strip is weighed. A much more recent test is the WADC Deposition Test illustrated in Figure 7 which was devised to simulate conditions to which oils are exposed in engines. Oil at 300°F. is circulated for 12 hours over an aluminum tube heated to 590°F. and through an oil screen. Weights of the tube and screen deposits are used to calculate "Deposition Number." Low numbers are indicative of less deposits formed. This test is stated to correlate well with engine deposits formed during military oil qualification runs.

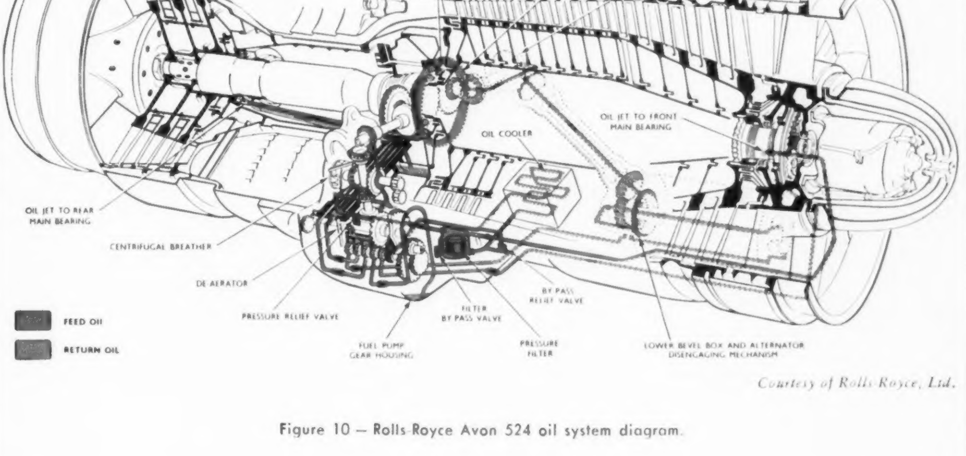
In more elaborate efforts to simulate engine conditions in the laboratory, test rigs have been designed which employ full-scale engine bearings operating

at high speeds and temperatures. In the United States, cooperative work has brought the High Temperature Bearing Test, shown in Figure 8, to final stages of development as the recognized standard bearing test for aircraft turbine oils. In this test a 100 mm. bore roller bearing is operated at 500°F. outer race temperature for 100 hours at 10,000 rpm with 500 pounds radial load. For MIL-L-7808 type oils, the temperature of the oil going to the bearing is controlled at 300°F. In the evaluation of higher temperature capability oils for advanced engines, oil temperature is increased to 400°F. Oil performance is rated from the standpoint of bearing deposits, mechanical condition and used oil condition. This very valuable test readily demonstrates the powerful influence of temperature on oil performance. Oils which easily pass the 100 hour test at the 300°F. oil condition routinely fail due to excessive deposits formation in less than 50 hours at the 400°F. oil condition. This is illustrated in Figure 9. Due to the high cost and large oil requirement of this test, its main utility is in the final stages of laboratory oil development work where by screening unsatisfactory oils its use can reduce the number of engine tests required. The British specification includes a full-scale bearing test which is run with step-wise bearing temperature increases until a limiting temperature is reached at which excessive deposits are formed. In neither of these tests is there any intent to fail the test bearing. On the contrary, the tests were devised to avoid failing bearings so that this variable would not complicate oil evaluations.

Load-Carrying Ability

Modern turbine engines contain a number of highly loaded parts which depend on the engine oil to maintain metal to metal separation. High speed gears and bearings are the most critical components in this regard. To date the primary emphasis has been on gear performance as increases in gear loading allow substantial engine weight decreases, particularly in turboprop engine reduction gears. Gear loading has been established by an oil's ability to prevent tooth scuffing, a high-load, short-time type of failure. Extensive service experience has shown, however, that operating just below the onset of gear scuffing will not always prevent fatigue failures such as gear pitch line pitting. Further reductions in design loads are required when such fatigue failures occur.

Two ways of increasing oil load-carrying ability are available to the oil manufacturer. Increasing oil viscosity is traditional and effective, but low temperature requirements such as mentioned earlier severely limit this approach. Extreme pressure (EP) agents which form readily sheared films at the contact surfaces are another method. This approach is commonly used in low viscosity synthetic oils which do not have sufficient load-carrying ability without such additives. The variety of usable EP agents is



Courtesy of Rolls-Royce, Ltd.

Figure 10 — Rolls-Royce Avon 524 oil system diagram.

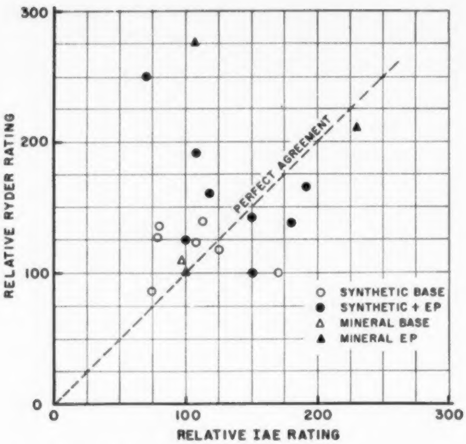


Figure 11 — Relationship of Ryder and IAE Gear test results referred to Grade 1100 mineral oil as 100. Note that only a very general correlation exists and that oil type has no clear-cut influence.

restricted by the corrosion resistance and other properties required of the oil. Unlike viscosity, the effectiveness of these additives is sensitive to contact pressures, sliding velocities and resulting surface temperatures which determine whether the proper chemical compound is formed at the sliding surface. This effect is illustrated in Figure 11 which shows the gear scuff limits of several oils evaluated by two types of gear testers.

Although considerable research has been carried out, no existing EP tester, such as the Four-Ball, SAE, Timken, etc., satisfactorily predicts oil load-carrying ability in turbine engine gears. It is, therefore, necessary to obtain this information in machines which use actual gears. In the Ryder machine two aircraft-type gears are run at 10,000 rpm which corresponds to a pitch line velocity of 8,000 feet per minute. The gears are progressively loaded until a predetermined percentage ($22\frac{1}{2}$) of tooth area is scuffed around the gear. New and scuffed gears are shown in Figure 12. Because each load is maintained only for 10 minutes, long term phenomena such as fatigue cannot be directly predicted. The test is also conducted at the relatively low bulk oil temperature of 165°F. Oils were originally rated in terms of the absolute load carried by the gears in pounds per inch of tooth width. To improve machine to machine reproducibility, "relative ratings" are now also reported as percentages of the load carried by a mineral reference oil (Grade 1100 aircraft engine oil). The British specification requires the use of the I.A.E. (Institute of Automobile Engineers) Machine which was originally developed to rate automobile gear oils. Scuff tests in this machine are conducted at two speeds with step-wise increases of load. Test oil ratings must be at least equivalent to those of a Grade 1100 mineral reference oil.

Since gear loading is critical in turboprop engine reduction gears, manufacturers of these engines generally conduct a full-scale engine reduction gear rig test prior to engine evaluation of an oil. A reduction gear test is usually of the same time duration as an engine type-test and is conducted at some specified gear over-load. This type of test has the advantage of studying oil performance with actual engine gears and other components such as bearings and pumps. It also allows the monitoring of oil changes which may take place during the run. However, the cost of this type of test is very high and precludes it from becoming a routine test for oil development and quality control during oil manufacture.

In addition to gear surface fatigue problems mentioned earlier, similar problems have occured upon occasion in anti-friction bearings. The distress here manifests itself in rolling element and/or race spalling or pitting. The exact mechanism of failure in these cases is not clear at this time; inter-granular corrosion or mechanical fatigue or a combination of these mechanisms may be involved. Various investigators are studying different factors which may influence this type distress. Here again a reduction in bearing load or an increase of oil viscosity form the traditional solution. Not enough results exist to clearly define the effects, if any, of variables such as differing base oil types and EP agents. In actual service, gear and bearing surface deterioration is not a widespread chronic problem when using current aircraft turbine oils, but research with respect to surface deterioration is timely in view of increased demands being placed on oils by increased temperatures and increased operating time on engine parts.

Low Temperature and Storage Stability

Aircraft turbine oils must not gel, separate or crystallize upon exposure to low temperatures. Accordingly, such oils must pass tests conducted at low temperatures to demonstrate that they are satisfactory from this standpoint. These tests comprise holding the oil at low temperatures for stated lengths of time and either visually examining them and/or measuring any increase in viscosity encountered. Pour point is normally specified to ensure low temperature oil mobility.

Long time storage, especially under adverse conditions, tends to deteriorate any oil. Some of the current synthetics may be less stable than mineral oils. The rate of deterioration is a function of several variables including oil formulation, storage temperature and the presence of water. To achieve maximum storage life, synthetic oils should be stored under dry, moderate-temperature conditions. Sealed containers are of material assistance in this

regard. Opened, partially-filled containers should be avoided not only from the standpoint of storage stability but also because they invite contamination of the oil by foreign material.

The SOD Lead Corrosion Test has been found to be sensitive to oil changes in storage. However, SOD Lead Corrosion results higher than specification maximums do not necessarily indicate that engine corrosion will occur upon use of the oil; some oils with high SOD Lead Corrosion results have been engine tested without causing corrosion of lead alloy bearing surfaces. Because information on this subject is incomplete, the use of oil having higher than specification maximum SOD Lead Corrosion values should be approached with caution.

Under satisfactory storage conditions, synthetic oils can be stored for a year or more. All concerned with these oils should be cognizant of their storage characteristics but not overly apprehensive if they are handled properly. Use on a "first-in, first-out" basis is helpful in maintaining an inventory of oil in satisfactory condition.

Volatility

As mentioned earlier, relatively high volatility at elevated temperatures was a major deficiency of light mineral oils. The need for low oil volatility is obvious. For example, in bearing compartments oil is finely dispersed in bearings at elevated temperatures and intimately mixed with compressor bleed air used to pressurize the compartments. The oil mist, vapor and air from the bearing compartments are carried back to the engine oil supply tank which is maintained at a pressure slightly above atmospheric but is vented overboard to relieve pressure as required. Under such conditions, a volatile oil would be lost overboard. This situation is alleviated by the relatively non-volatile synthetic oils and is one of the main advantages of this type oil.

Oil volatility is indicated indirectly by flash point and directly measured by an evaporation test as shown in Table I. The latter test comprises heating the oil under prescribed conditions for a fixed time and measuring the amount of oil lost through evaporation.

Foam Resistance

Turbine engine lubrication systems contain a relatively small amount of oil (5 to 10 gallons), which is circulated at high velocity. High speed bearings and gears intimately mix air and oil. Bearing and gear compartments operate with dry sumps and scavenge pumps. The pumps, therefore, mix considerable air with the oil. Means of oil de-aeration are included in the oil system, but the small available tank volumes together with high system velocities severely stress these devices. It is essential that oil and air separate rapidly without forming a foam which could lead to inadequate gear and bearing lubrication and prevent efficient oil scavenging. Such foam could also be expelled through oil tank vents with consequent loss of oil.

Oil foaming tendencies are measured by blowing air at a controlled rate for a specified period of time through an oil sample held at constant temperature. The volume of foam immediately after blowing and the time for total foam collapse are limited by most specifications. Synthetic oils have relatively good resistance to foaming and their foams usually collapse readily but it is necessary to eliminate sudden

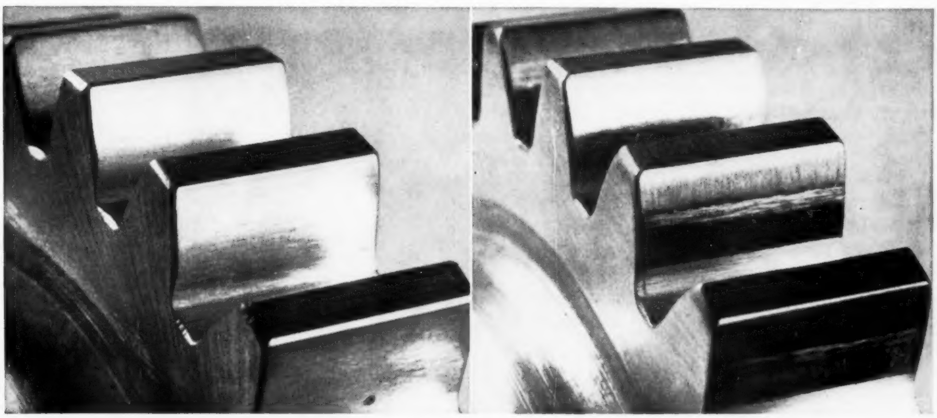
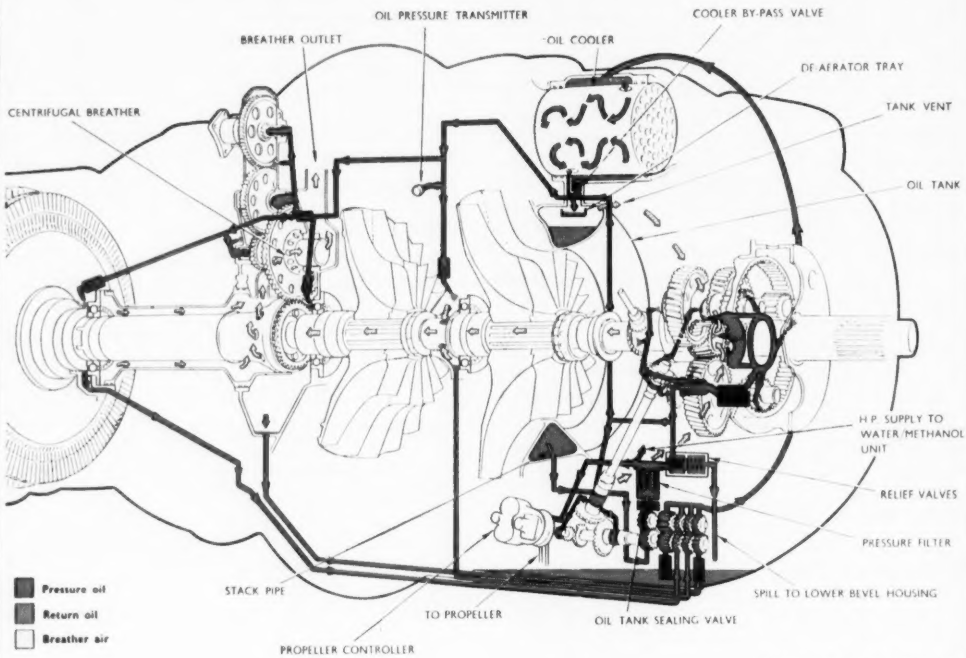


Figure 12 —

New gear.

Failed gear from Ryder test. Note radial scuffing both above and below axial pitch band.



Courtesy of Rolls-Royce, Ltd.

Figure 13 — Rolls-Royce Dart oil system.

volume expansion and changes in flow directions as well as other mechanical system features which promote air bubble entrainment in the oil stream. Contaminants such as dirt, thread lubricants, etc., are deleterious to good oil foam resistance.

It is of interest that apparent synthetic oil foaming has been encountered in the laboratory upon heating oil containing water in a separate liquid phase. The rapid evolution of vapor from the water resulted in entraining oil with the appearance of extreme foaming. This same phenomenon could conceivably occur in engines with the consequent oil "spewing" being attributed erroneously to air-induced oil foaming.

Compatibility

Each specification requires that every oil under consideration for approval shall be compatible with the oils already approved. Compatibility is usually demonstrated by mixing oils in various proportions and observing the mixture over a temperature range for characteristics not found with the oils tested separately. Mixing of different brands of synthetic oil in an engine is undesirable, as it is in the case of any oil. While no gross ill-effects have been noted by the Military Services who routinely mix oil brands, engine manufacturers either severely limit or entirely prohibit oil mixing in commercial engines.

Toxicity and Handling

In general, synthetic oils may be classed in the same category as mineral oils, both in the liquid and vapor states, with regard to toxicity. As in the case of mineral oil, ingestion and prolonged skin contacts are to be avoided.

Paints, electrical insulation and elastomer materials resistant to synthetic oils should be employed wherever they will come into contact with such oils. Natural rubber, certain synthetic rubbers, plastics and conventional paints are readily deteriorated by synthetic oils.

Rust Protection

Some engine manufacturers specify the use of synthetic preservative oil to provide extra protection against rusting of parts during engine storage. The

avoidance of rust on anti-friction bearing working surfaces is important as small rusted areas could become the starting points for ultimate bearing failure. Preservative oils are essentially the regular synthetic oils plus a special additive which will enable the oil to pass a 144 hour rusting test of steel panels in an atmosphere of 100 percent relative humidity at 120°F. The U. S. Military Services no longer stipulate that preservative oil be employed basis their information showing satisfactory storage experience without the use of such oil.

OIL PERFORMANCE IN ENGINES

The foregoing has summarized requirements which aircraft turbine oils must fulfill and the laboratory procedures used to evaluate the abilities of oils to meet the requirements. While these procedures can be used effectively to screen prospective oils, the final criterion is performance in actual engines. The performance evaluation of oils in engines can be divided into two categories: Qualification Evaluations and Service Performance.

Qualification Evaluations

The engine testing required to demonstrate that an oil is suitable for its intended use is at the option of the qualifying organization. Such testing may entail relatively short (100-150 hours) test stand runs or lengthy endurance runs of 1000 hours or more. Sometimes both short and extended runs are required as well as flight testing. This testing may be in turbojet and/or turboprop engines.

The short-term engine runs are usually under more severe operating conditions than the oil would be expected to experience continuously in actual service. Such tests are sometimes accelerated by operating at above-normal oil temperatures and engine over-load conditions. Endurance runs may be made at somewhat less severe conditions to simuuate engine service when installed in aircraft. Flight evaluations may be under accelerated or normal engine operating conditions.

In all cases, the performance of the oil is checked by critical examination of engine operation, engine condition after the test and used oil condition. Bearings and housings, gears and cases, oil lines, jets, screens and breather lines are examined for deposits. Metal parts in contact with oil are inspected for corrosion. Bearings and gears are scrutinized for evidence of wear and fatigue. Elastomers are checked for cracking, swelling or other deterioration. Records of oil consumption and used oil condition with regard to deterioration from new oil condition are also considered in arriving at a final decision on oil performance.

In numerous instances it has been found that oils will pass the many laboratory tests only to fail the qualification engine tests with regard to one or more of the performance parameters. Accordingly, great importance is attached to qualification engine testing and only superior oils are accepted.

Service Performance

The service performance of an oil is a reflection of not only the properties of the oil itself but also of its subsequent handling and the engine environment to which it is subjected. It, therefore, requires diligence on the part of both the oil supplier and user to obtain maximum oil performance.

Stringent control is exercised in the manufacturing and packaging of aircraft turbine oils to assure delivery of the oil in best possible condition for use. To maintain the oil in this condition until it is placed in the engine requires that the oil be properly stored and handled to avoid contamination. This is true of any lubricant but particularly true of aircraft turbine oils in view of their critical applications.

The engine environment to which an oil is subjected varies according to differences in engine type and design. With a given engine it is further affected by installation, method of operation and maintenance practices. Clearly, the service performance of an oil is a complex matter in which are summed-up the effects of numerous variables. Consequently, the performance of a given oil can be expected to vary in different service applications of the same engine type or in different engine types, even in similar service.

The service performance of synthetic aircraft turbine oils to date has been generally satisfactory. This experience has shown, however, that in some current and numerous future engines a major area of desired improvement is ability to withstand elevated temperatures; this will be discussed further below.

Used Oil

The ideal aircraft turbine oil would never change in use as the result of exposure to extreme temperatures, oxidizing atmospheres, various equipment materials, nor be contaminated with dirt, water, thread lubricants, fuel, engine wear particles, etc. It is therefore important to establish the suitability of the used oil for further service. The answer to this question fundamentally lies with the equipment in which the oil is being used. Obviously, the oil is in suitable condition only if its performance is acceptable in the equipment in which it is employed. The importance of used oil is emphasized by the fact that the engine runs essentially its entire time between overhauls on used oil because an oil becomes "used" as soon as the engine is started.

It follows that it is necessary to closely relate used oil and engine condition. This practice has been very successfully employed over the years in connection with the use of mineral aircraft engine oil in aircraft

reciprocating engines and there is every reason to extend this technique to aircraft turbine engines. The technique includes periodically analyzing samples of used oils and inspecting engines at overhaul to assess oil performance. By careful study, laboratory test results on used oil are correlated with factors such as time between oil drains and engine overhauls, engine operational procedures, engine mechanical and maintenance changes, etc. In this way, the optimum engine-oil relationship is established. This requires experience, close cooperation and diligence on the part of the oil supplier and user, such as practiced so satisfactorily in the case of reciprocating engines.

The numerous specification laboratory tests for new oils can be employed in used oil testing but not necessarily all of these tests are required when considering used oil. Indeed, it is rarely possible to run complete specification tests on used oils because of the large sample required relative to the amount of oil in the engine system. Some tests which are not included in new oil specifications are useful in evaluating used oil. Experience with used aircraft turbine oils has shown that very simple tests such as appearance and odor can produce very revealing information to the experienced observer. In addition, used oil specific gravity, water and sediment content data can be useful. Analysis of any sediment in the oil can be most valuable in diagnosing internal engine condition; for example, the presence of engine construction materials in the oil has been used to indicate mechanical malfunctioning or impending mechanical failure. Flash point test results can indicate oil contamination by turbine fuel. Analysis for other contaminants can be helpful for various reasons, including ascertaining the reason for any excess engine deposits, wear, corrosion, etc. Tests for oil viscosity, oxidation and corrosion resistance and foaming, etc., can be helpful in used oil testing if properly applied and interpreted in terms of oil performance in the engine. Except for special-purpose investigations, gear and bearing tests are not normally conducted on used oils; gear load-carrying ability generally increases in service due to the presence of oil oxidation products.

From the foregoing it is obvious that oil drain intervals are a function of engine and used oil condition. Some engines and operations permit longer times between drains than others. These intervals are best set by experimentation with various intervals and close observation of the condition of the oil and engine as longer drain periods are tried. During such a program an extensive array of tests is conducted on the used oil to establish its condition. The program also serves to provide background data for comparison of used oil condition when any unusual engine or oil condition is suspected. Whenever oil condition is suspect, the oil should be drained and replaced. It should be remembered, however, that poor oil condition can result from faulty engine operation and mere oil replacement will not necessarily solve the basic difficulty. Intelligent monitoring of used oil analyses, therefore, can serve as a valuable part of engine trouble shooting.

FUTURE OIL REQUIREMENTS

A number of current engines operate at bulk oil temperatures of the order of 250°F. and bearing temperatures up to approximately 450-500°F. In advanced engines, bulk oil temperatures in the neighborhood of 400°F. are forecast along with higher bearing temperatures. These higher temperatures are associated with higher engine power outputs and aerodynamic heating effects which preclude using ram air as an oil cooling medium in air/oil heat exchangers. To a certain extent, fuel can be used to cool oil in fuel/oil heat exchangers, but there are fuel temperature limitations governed by the formation of high temperature fuel system deposits. The use of refrigeration to cool oil is impractical due to the severe weight penalties involved and complexity of the equipment required. In view of these factors, target Military Specification MIL-L-9236A has been issued which covers lubricants having higher temperature capability than presently available oils. Current lubricants technology indicates that if the desired high temperature capability is to be achieved, some sacrifice in low temperature performance may be required since the most promising materials for high temperature use are usually more viscous at low temperatures than present oils. It is considered too early to state what materials will be employed for the higher temperature type oils. In addition to use in advanced engines, there is promise that the higher temperature type oils will be useful in existing engines from the standpoint of reducing deposits and oil deterioration due to elevated temperatures, thereby resulting in increased time between oil drains and/or engine overhauls.

SUMMARY

Very exacting and numerous demands are placed on oils for modern aircraft turbine engines. To a large measure, the success of this type powerplant has been made possible by the availability of oils which fulfill these stringent requirements. The development of such oils entails close coordination between the oil developer and engine builder to ensure that their finished products will perform together efficiently. In service, this team is joined by the oil and engine user whose experience is, in the final analysis, the criterion by which the oil's performance is judged. With continued cooperation and understanding of each other's problems there is optimisim that additional progress in aircraft turbine lubrication can be expected.

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